PB86-215258

# Interim Indoor Radon and Radon Decay Product Measurement Protocols

(U.S.) Office of Radiation Programs
Washington, DC

Apr 86

U.S. Department of Commerce
National Technical Information Service
PUBLIC

PB86-215258

United States
Environmental Protection
Agency

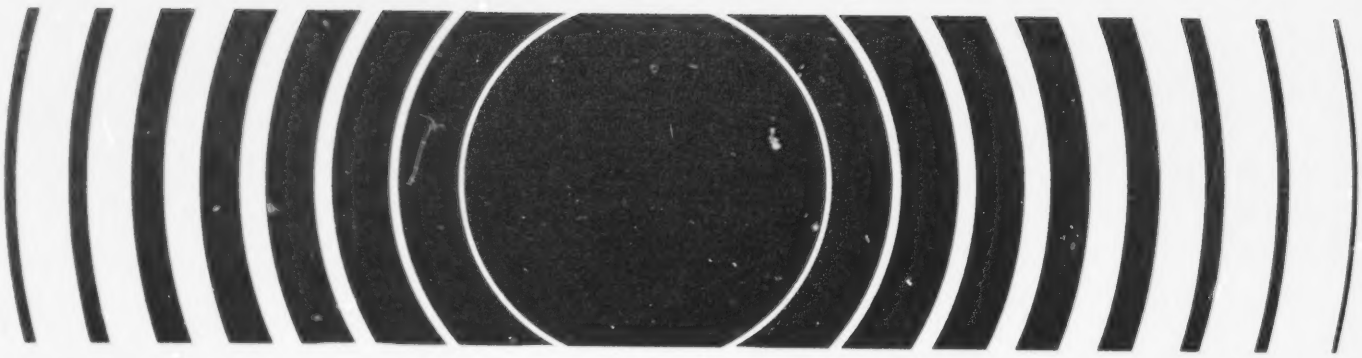
Office of
Radiation Programs
Washington, D.C. 20460

EPA 520/1-86-04
April 1986

Radiation

EPA

# Interim Indoor Radon and Radon Decay Product Measurement Protocols



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA 520/1-86-04

# INTERIM INDOOR RADON AND RADON DECAY PRODUCT MEASUREMENT PROTOCOLS

U.S. Environmental Protection Agency

Office of Radiation Programs

February 1986

M. Ronca-Battista
P. Magno
S. Windham
E. Sensintaffar

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | |
|---|---|
| 1. REPORT NO. EPA 520/1-86-04 | 2. |
| 3. RECIPIENT'S ACCESSION NO. PB86-215258/AS | |
| 4. TITLE AND SUBTITLE<br>Interim Indoor Radon and Radon Decay Product Measurement Protocols | 5. REPORT DATE<br>April 1986 |
| | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>Office of Radiation Programs | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Office of Radiation Programs<br>401 M Street, S.W.<br>Washington, D.C. 20460 | 10. PROGRAM ELEMENT NO. |
| | 11. CONTRACT/GRANT NO. |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Environmental Protection Agency<br>401 M Street, S.W.<br>Washington, D.C. 20460 | 13. TYPE OF REPORT AND PERIOD COVERED |
| | 14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report provides EPA's procedures for measuring radon concentrations in houses with continuous radon monitors, charcoal canisters, alpha-track detectors, and grab radon techniques. It also provides procedures for measuring radon decay product concentrations with a continuous working level monitor, a radon progeny integrating sampling unit (RPISU), and grab radon decay product methods. Specifications for the location of the measurement, the house conditions during the measurement, and minimum requirements for quality control are included in each procedure.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| | | |

| 18. DISTRIBUTION STATEMENT | 19. SECURITY CLASS *(This Report)* | 21. NO. OF PAGES |
|---|---|---|
| | Unclassified | 62 |
| | 20. SECURITY CLASS *(This page)* | 22. PRICE $11.95 |

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

F

CONTENTS


PAGE

EXECUTIVE SUMMARY ..... iii

Section 1: GENERAL CONSIDERATIONS ..... 1

1.1 Introduction and Background ..... 1

1.2 Standardized Measurement Conditions ..... 1

1.2.1 House Conditions ..... 2
1.2.2 Location Selection ..... 3

1.3 Quality Assurance Objectives ..... 4

Section 2: RADON MEASUREMENT PROTOCOLS ..... 7

2.1 Protocol for Using a Continuous Radon Monitor to Measure Indoor Radon Decay Product Concentration ..... 7

2.2 Protocol for Using Alpha-Track Detectors to Measure Indoor Radon Concentration ..... 11

2.3 Protocol for Using Charcoal Canisters to Measure Indoor Radon Concentrations ..... 19

2.4 Protocol for the Determination of Indoor Radon Concentration by Grab Sampling ..... 26

Section 3: RADON DECAY PRODUCT MEASUREMENT PROCEDURES .. 33

3.1 Protocol for Using a Continuous Working Level Monitor to Measure Indoor Radon Decay Product Concentration ..... 33

3.2 Protocol for Using Radon Progency Integrated Sampling Units (RPISU) to Measure Indoor Radon Decay Product Concentration ..... 37

3.3 Protocol for the Determination of Indoor Radon Decay Product Concentration by Grab Sampling ..... 43

CONTENTS--Continued


| | PAGE |
|---|---|
| REFERENCES ..... | 49 |
| Appendix A: Supplementary Information for Grab Radon Sampling ..... | A-1 |
| Appendix B: Supplementary Information for Grab Radon Decay Product Sampling ..... | B-1 |

## EXECUTIVE SUMMARY

There are many organizations now performing indoor radon and radon decay product measurements or planning measurement programs. It is important that different groups follow consistent procedures, to enable valid intercomparison of measurement results from different programs.

This document outlines procedures for making measurements and describes standardized house conditions that should exist at the time of the measurement. The procedures outlined here are those that have been evaluated by the Environmental Protection Agency (EPA) and found to be satisfactory; procedures for other instruments may be added as they are evaluated by EPA.

The procedures specify that measurements be made where and when the radon and radon decay product concentrations are likely to be the most stable: in a closed house with a minimum level of ventilation. Such measurements will generally be higher than the average levels to which the occupants are exposed. Specifying standard conditions is necessary for two reasons. First, the primary objective of the protocols is to produce measurement results that can be related to potential exposures in the house and that have the smallest possible variability with the technique, i.e., that are reproducible. Second, it is important to quantitatively estimate the variability; and that can only be estimated from data taken under similar conditions. Since average living conditions are difficult to define and reproduce, we have defined the standardized conditions as closed-house conditions.

This document provides procedures for measuring radon concentrations with continuous radon monitors, charcoal canisters, alpha-track detectors, and grab radon techniques. It also provides procedures for measuring radon decay product concentrations with a continuous working level monitor, a radon progeny integrating sampling unit (RPISU), and grab radon decay product methods. Specifications for the location of the measurement, the house conditions during the measurement, and minimum requirements for quality control are included in each procedure.

## Section 1: GENERAL CONSIDERATIONS

### 1.1 Introduction and Background

Increases in the risk of lung cancer due to exposure to radon and its decay products are of growing concern to State and Federal health officials. There is increased awareness that indoor radon concentrations may be greater than had once been estimated and that there are areas in the country where the indoor levels are such that even short-term exposures can cause a significant increase in risk. It is extremely important to locate houses with the potential for causing high exposures. However, the urgency to measure concentrations in houses can result in unreliable or misleading data.

There are many Federal, State, university, and private organizations now performing measurements or planning measurement programs. Consistent procedures must be followed to permit valid intercomparison of measurement results from different programs.

Problems encountered when measuring indoor radon and radon decay product (RDP) concentrations include variability due to (1) nonstandardized procedures, (2) different house conditions prior to and during the measurement, (3) seasonal and other weather conditions, and finally, different interpretations of the results. The protocols in this document reduce the uncertainty caused by these sources of variability by providing standardized measurement procedures and criteria for house and weather conditions that can exist prior to and during the measurement. The primary objective of the protocols is to provide procedures for making reproducible measurements, with a known and limited variability.

This document first presents some general considerations relevant to all the instruments discussed, then outlines seven technique-specific procedures. The procedures provide information needed by an experienced user to calibrate, deploy, and operate the instruments as well as to develop an adequate quality assurance program for instrument use. Each technique-specific protocol includes sufficient information to allow it to be used independently of the entire document.

### 1.2 Standardized Measurement Conditions

These protocols specify that measurements be made when the radon and radon decay product concentrations are likely to be the most stable, e.g., in a closed building with a minimum level of ventilation. Such measurements will generally be higher than the average concentrations to which the occupants are exposed. Specifying that measurements be made under standardized conditions is necessary for the following two reasons.

First, the primary objective of the protocols is to produce measurement results that can be related to either potential or actual exposures in the house and that have the smallest possible

variability with the technique, i.e., that are reproducible. The most reproducible measurements are those taken when the house conditions are standardized, with the house closed, and after sufficient time has been allowed for the concentrations to stabilize. To achieve such a measurement, the ventilation rates should be as low as possible. Reproducible results are of utmost importance when measuring indoor radon or RDP concentrations in a home before and after it undergoes remedial action, so that the effectiveness of the remedial action can be measured. Having a high degree of confidence that the results of a measurement represent the radon or RDP concentration in a building under standardized conditions is important when deciding whether remedial action is necessary or when comparing the measurement results to guidance levels.

Second, it is important to quantitatively estimate the variability associated with the result of a measurement. This variability can be estimated only from data taken under similar conditions, and since average living conditions are difficult to define and to reproduce, specifying standard conditions allows for valid application of the estimates of error.

The following paragraphs discuss how these standard conditions are to be achieved.

### 1.2.1 House Conditions

The measurement should be made under "closed-house" conditions. To a reasonable extent, windows and external doors should be closed (except for normal entrance and exit). Normal entrance and exit includes a brief opening and closing of a door, but an external door should not be left open for more than a few minutes. In addition, external-internal air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operating. For measurement periods of 3 days or less, these conditions should exist for 12 hours prior to beginning the measurement. It may be difficult to verify these conditions or to implement them for an extended period, but they should be adhered to as closely as is reasonable.

Closed-house conditions will generally exist as normal living conditions in northern areas of the country when the average daily temperature is less than 40°. Depending on the area, this can encompass the winter period from late fall to early spring.

There are two reasons why measurements in northern climates should be made during the winter season. First, during the winter, closed-house conditions exist as normal living conditions. Thus, there is a greater assurance that the proper conditions will exist prior to and during the measurement period. Second, information on factors that influence indoor radon concentrations indicate that concentrations during the winter are generally higher than during the summer.

If, however, it is necessary to make measurements during the summer when closed-house conditions are not the normal living conditions, then it will be necessary to establish some means for providing reasonable assurance that closed-house conditions will exist prior to and during the measurements.

Organizations performing measurements in southern areas that do not experience extended periods of cold weather should evaluate seasonal variations in living conditions and identify if there are time periods when closed-house conditions normally exist. If such periods exist, that is when measurements should be conducted. Air conditioning systems that recycle interior air can be operated during the closed-house conditions.

To better address measurements made during summer months in cold climates and at any time in warm climates, additional data are needed.

Measurements of 3 days or less should not be conducted if severe storms with high winds are predicted. Severe weather will affect the measurement results in the following ways. First, a high wind will increase the variability of radon concentration because of wind-induced differences in air pressure between the house interior and exterior. Second, rapid changes in barometric pressure increase the chance of a large difference in the interior and exterior air pressures, therefore changing the rate of radon influx. Weather predictions available on local news stations will provide sufficient information to determine if this criterion is satisfied.

### 1.2.2 Location Selection

The location of the measurement within a room should be decided with the objective of measuring the most stable concentrations. The following criteria should be applied, in order of importance, when selecting the measurement location within a room.

1. The measurement should be taken in an area away from drafts caused by heating, ventilation, air conditioning (HVAC) vents, doors, windows, and fireplaces. This will reduce the influence of changes in ventilation and condensation nuclei concentration on radon and RDP concentrations.

2. The measurements should be taken away from exterior house walls to reduce the effect of ventilation through cracks in the walls.

3. The passive device or the air intake of an instrument should be placed at least 50 centimeters (20 inches) above the floor to reduce possible effects of plate-out or drafts near the floor.

## 1.3 Quality Assurance Objectives

The object of quality assurance is to ensure that data are scientifically sound and of known precision and accuracy. There are several aspects of quality assurance that should be included in any measurement program. These are: controlled calibrations, replicate measurements, background measurements, and routine sensitivity checks.

Controlled calibrations are samples collected or measurements made in a known radon environment such as a calibration chamber. Detectors requiring laboratory readout, such as charcoal canisters, alpha-track detectors, and RPISU samplers, would be exposed in the calibration chamber and then analyzed. Instruments providing immediate results, such as continuous working-level monitors and continuous radon monitors, should be operated in a chamber to establish calibration.

There are two types of calibration measurements that should be made for alpha-track detectors and charcoal canisters. The first are the measurements that must be conducted to determine and verify the conversion factors used to derive the concentration results. These measurements, commonly called spiked samples, are done at the beginning of the measurement program and periodically thereafter. The second calibration measurements are performed to monitor the accuracy of the system. These are called blind calibration measurements and consist of detectors that have been exposed in a radon calibration chamber. They are not labelled as such when sent to a processing laboratory.

Background measurements, or blanks, should also be frequently conducted. Such measurements should be made using unexposed passive detectors or should be instrument measurements conducted in very low (outdoor) radon concentration environments and separated from the operating program. These should be generally equivalent in frequency to the spiked samples and should also not be identified as blanks when submitted for analysis to external laboratories. In addition to these background measurements, the organization performing the measurements should calculate the lower limit of detection (LLD) for the measurement system. This LLD is based on the system's background and can restrict the ability of some measurement systems to measure low concentrations.

Duplicate measurements provide an estimate of the precision of the measurement results. Duplicate measurements should be included in at least 10 percent of the samples. If enough measurements are made, the number of duplicates may be reduced, as long as enough are used to analyze the precision of the method.

A quality assurance program should include written procedures for obtaining the preceding objectives. Also a system for monitoring the results of the four types of quality assurance

measurements should be continuously maintained and available for inspection.

The EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA Quality Assurance Officer by calling (Federal Telecommunications System (FTS) or 703) 557-7380, or call 800-334-8571, extension 7131, for further information about this program.

## Section 2: RADON MEASUREMENT PROTOCOLS

### 2.1 PROTOCOL FOR USING A CONTINUOUS RADON MONITOR TO MEASURE INDOOR RADON CONCENTRATION

#### 2.1.1 Purpose

This protocol provides guidance for using a continuous radon monitor (CRM) to measure indoor radon concentrations accurately and to obtain reproducible results. Following the protocol will help assure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce measurements of radon concentrations representative of standardized closed-house conditions. Such measurements of closed-house concentrations have a smaller variability and are more reproducible than measurements made when the house conditions are not controlled.

#### 2.1.2 Scope

This protocol covers, in general terms, the sample collection and analysis method, the equipment needed, and the quality control objectives of measurements made with a CRM. It is not meant to replace an instrument manual, but rather provides guidelines that should be incorporated into standard operating procedures. More information about the procedures may be obtained from the U.S. EPA Office of Radiation Programs (ANR-460), 401 M Street, S.W., Washington, D.C., 20460.

#### 2.1.3 Method

A CRM samples the ambient air by pumping air into a scintillation cell after passing it through a particulate filter that removes dust and radon decay products. As the radon in the air decays, the ionized radon decay products plate out on the interior surface of the scintillation cell. The radon decay products decay by alpha emissions, and the alpha particles strike the ZnS(Ag) coating on the inside of the scintillation cell, causing scintillations to occur. The scintillations are detected by the photomultiplier tube in the detector, which generates electrical signals. The signals are processed by the electronics, and the results are either stored in the memory of the CRM or printed on paper tape by the printer. The CRM must be calibrated in a known radon environment to obtain the conversion factor used by the electronics to convert count rate to radon concentration.

The CRM may be a flowthrough-cell type or the periodic-fill type. In the flowthrough-cell type air continuously flows into and through the scintillation cell. The periodic-fill type fills the cell once each preselected time interval, counts the scintillations, then begins the cycle again.



Preceding page blank

### 2.1.4 Equipment

In addition to the CRM, equipment needed includes a readout device and printer (if not part of the CRM), an air-flow rate meter, and aged air or nitrogen to pump through the CRM to measure the background count rate.

### 2.1.5 Pre-development Testing

The CRM should be carefully tested before and after each measurement to:

- Verify that the correct input parameters and the unit's clock are set properly.
- Verify the operation of the pump.

After every 1000 hours of operation the unit should be examined to check the background count rate by purging with clean, aged air or nitrogen in accordance with the procedures identified in the operating manual for the instrument. In addition, the background count rate should be more frequently monitored by operating the instrument in an outdoor or other low radon environment.

In addition, participation in a laboratory intercomparison program should be conducted at least semiannually to verify that the conversion factor used by the CRM is accurate. This is done by comparing the unit's response to a known radon concentration. At this time, the correct operation of the pump should be verified and the flow rate measured.

### 2.1.6 Measurement Criteria

The following house conditions should exist prior to and during a measurement, to standarize the measurement conditions as much as possible.

- The measurement should be made under closed-house conditions. To the extent reasonable, windows and external doors should be closed (except for normal entrance and exit) for 12 hours prior to and during the measurement period. Normal entrance and exit includes opening and closing of a door, but an external door should not be left open for more than a few minutes. These conditions are expected to exist as normal living conditions during the winter in northern climates. For this reason and other reasons discussed in section 1.2.1, measurements should be made during winter periods whenever possible.

- Internal-external air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operating during the measurement and for at least 12 hours before the measurement is initiated.

- In southern climates or when the measurements must be made during a warm season, the standardized closed-house conditions are satisfied by meeting the criteria just listed. These criteria can be most conveniently satisfied if the measurement is begun in the morning, after the occupant has been instructed to keep the windows closed during the night and not to open them until the measurement has been completed. Air conditioning systems that recycle interior air may be operated. The closed-house conditions must be more rigorously verified and maintained, however, when they are not the normal living conditions.

- The measurement should not be conducted if severe storms with high winds are predicted during the measurement period. Weather predictions available on local news stations will provide sufficient information to determine if this condition is satisfied.

2.1.7 Deployment and Operation

2.1.7.1 Location Selection

The following criteria should be applied to select the location of the CRM within a room.

- The measurement should not be made near drafts caused by heating, ventilating and air conditioning (HVAC) vents, doors, windows, and fireplaces.

- The measurement location should not be close to the outside walls of the house.

- The unit should be placed on a table or stool so that the air intake is at least 50 centimeters (20 inches) from the floor.

2.1.7.2 Operation

The CRM should be programmed to run continuously, recording the hourly integrated radon concentration measured and, if applicable, the total integrated average radon concentration. The sampling period should generally not be less 24 hours. An increase in operating time decreases the uncertainty associated with the measurement result.

Care should be taken to eliminate data that is produced before equilibrium conditions have been established in a flow-through cell. Generally, conditions stabilize after the first several hours during which the measurements are very low and should be discarded. After this period, the periodic results should be averaged to obtain an integrated measurement result.

2.1.7.3 Documentation

It is important that the operator of the CRM records enough information about the measurement in a permanent log so that data interpretations and comparisons can be made. This information includes:

- Start and stop times and date of the measurement.
- Information about how the standardized conditions, as previously specified, were satisfied.
- Exact location of the instrument, on a diagram of the room and house, if possible.
- Other easily obtained information that may be useful, such as the type of house, type of heating system, existence of crawl space, occupants smoking habits, and operation of humidifiers, air filters, electrostatic precipitators, or clothes dryers.

2.1.8 Quality Assurance

The elements of a quality assurance program for the CRM are:

- Calibration in a radon-exposure calibration chamber at least every 6 months, or after instrument repair or modification.
- Background count-rate checks before and after approximately 1000 hours of operation.

The EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA Office of Radiation Programs Quality Assurance Officer by calling (FTS or 703) 557-7380 or call 800-334-8571, extension 7131, for further information about this program.

## 2.2 PROTOCOL FOR USING ALPHA-TRACK DETECTORS TO MEASURE INDOOR RADON CONCENTRATION

### 2.2.1 Purpose

This protocol provides guidance for using an alpha-track detector (ATD) to obtain accurate and reproducible measurements of indoor radon concentrations. Following the protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce measurements of radon concentration representative of standardized, closed-house conditions. Such measurements of closed-house concentrations have a smaller variability and are more reproducible than measurements made when the house conditions are not controlled.

### 2.2.2 Scope

This procedure covers, in general terms, the equipment, procedures, and quality control objectives to be used when performing the measurements. This document provides guidelines to be adopted into standard operating procedures. More information about the procedures may be obtained from the U.S. EPA Office of Radiation Programs (ANR-460), 401 M Street, S.W., Washington, D.C., 20460.

### 2.2.3 Method

An alpha-track detector (ATD) consists of a small piece of plastic enclosed in a container with a filter-covered opening. Alpha particles emitted by the radon decay products in air strike the plastic and produce submicroscopic damage tracks. At the end of the measurement period, the detectors are returned to a laboratory, where the plastic is placed in a caustic solution that accentuates the damage tracks so they can be counted using a microscope or an automated counting system. The number of tracks per unit area is correlated to the radon concentration in air, using a conversion factor derived from data generated at a calibration facility.

Many factors contribute to the variability of the ATD results, including differences in the detector response within and between batches of plastic, non-uniform plateout of decay products inside the detector holder, differences in the number of tracks used as background, variations in etching conditions and differences in readout. The variability in ATD results decreases with the number of net tracks counted, so counting more tracks over a larger area of the detector will reduce the uncertainty of the result. In addition, deploying duplicate ATDs will reduce the error. However, if cost considerations make it necessary to deploy single ATDs, the data obtained should be evaluated and used taking into consideration the relative errors associated with counting the area and number of net tracks specified to the processing laboratory.

### 2.2.4 Equipment

Alpha-track detectors are available from commercial suppliers. These suppliers offer contract services in which they provide the detector and subsequent data readout and reporting for a fixed price. Establishing an in-house capability to provide packaged detectors, a calibration program, and a readout program would probably not be practical or economically advantageous. Therefore, details for establishing the analytical aspects of an ATD program will be omitted from this protocol. If additional details are desired, they have been reviewed by Fleischer and Lovett (F165; Lo69).

Assuming ATDs are obtained from a commercial supplier, the following equipment is needed to initiate monitoring in a house:

- The alpha track detector in an individual, sealed container, such as an aluminized plastic bag to prevent extraneous exposure before deployment,
- A means to attach the ATD to its measurement location, if it is to be hung from the wall or ceiling,
- Instruction sheet for the occupant, and a shipping container and, if it is to be mailed, a prepaid mailing label for returning the detector to the laboratory,
- At the time of retrieval, some means (such as tape) will be needed to reseal the detector prior to returning it to the supplier for analysis.

### 2.2.5 Predeployment Considerations

The plans of the occupant during the proposed measurement period should be considered before deployment. The ATD measurement should not be made if the occupant knows he will be moving during the period. Deployment should be delayed until the new occupant is settled in the house. Likewise, the measurement should be delayed if the occupant is planning remodeling, changes in the heating, ventilating and air conditioning (HVAC) system, or other modifications that may influence the radon concentration during the period.

### 2.2.6 Measurement Criteria

The following house conditions should exist during the measurement period, to standardize the measurement conditions as much as possible.

- To a reasonable extent, the house should be closed, with all windows and external doors closed (except for normal extrance and exit) during the measurement period. These conditions are expected to exist as normal living

conditions during the winter in northern climates. For this reason and other reasons discussed in section 1.2.1, ATD measurements (other than 12-month measurements) should be conducted during the winter whenever possible.

- o Internal-external air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operated.

- o In warm conditions, the standardized conditions are satisfied by the criteria just listed. Air conditioning systems that recycle interior air can be operated. The closed-house criteria must be more rigorously verified and maintained, however, when they do not exist as normal living conditions. For a 3-month sampling period, however, a few days with the windows open will not invalidate the measurement.

A 12-month ATD measurement will provide information about the concentrations in the house during an entire year, so the closed-house conditions do not have to be satisfied for a valid 12-month deployment.

2.2.7 Deployment

2.2.7.1 Timely Deployment

A group of ATDs should be deployed into houses as soon as possible after delivery from the supplier. Groups should not order more ATDs than they can reasonably expect to install within the following few months to minimize chances of high background exposures. If the storage time exceeds more than a few months, the background exposures from a sample of the stored detectors should be assessed. Consult the manufacturer's instructions regarding storage and background determination.

2.2.7.2 Location Selection

The following criteria should be applied to select the location of the detector within a room.

- o A position must be selected where the ATD will not disturbed during the measurement period.

- o The detector should not be placed near drafts caused by HVAC vents, windows, doors, etc. Avoid locations near excessive heat, such as fireplaces.

- o The detector should not be placed close to the outside walls of the house.

It is usually convenient to suspend the detector from the ceiling. The detector should be positioned at least 20 centimeters (8 inches) below the ceiling. If the detector is installed during a site visit, the final site selected should be shown to the home occupant to be certain it is acceptable for the duration of the measurement period.

The sampling period is begun when the protective cover or bag is removed. Cut the edge of the bag or remove the cover so that it can be reused to reseal the detector at the end of the exposure period. Inspect the detector to make sure it is intact and has not been physically damaged in shipment or handling.

Fill in the information called for with the detector. Also, record the detector serial number in a log book along with a description of the location in the house in which the detector was placed. If during the exposure period it is necessary to relocate the detector, make certain it is noted in the log book, along with the date it was relocated.

### 2.2.8 Retrieval of Detectors

At the end of the measurement period, the detector should be inspected for damage or deviation from the conditions entered in the log book at the time of deployment. Any changes should be noted in the log book. The date of removal is entered on the data form for the detector and in the log book. The detector is then resealed using the protective cover or bag with the correct serial number for that detector or the cover originally provided. If a bag is used, the open edge of the bag is folded several times and resealed with tape. If the bag or cover has been destroyed or misplaced, the detector should be wrapped in several layers of aluminum foil and taped shut. After retrieval, the detectors should be returned as soon as possible to the analytical laboratory for processing.

### 2.2.9 Documentation

It is important that enough information about the measurement is recorded in a permanent log so that data interpretations and comparisons can be made. Information that should be recorded includes:

- The start and stop dates of the measurement.
- Whether standardized conditions, as previously specified, are satisfied.
- Exact location of the ATD(s), on a diagram of the room and house if possible.

- o Other easily gathered information that may be useful, such as the type of house, type of heating system, existence of crawl space, occupants smoking habits, operation of humidifiers, air filters, electrostatic precipitators, and clothes dryer.

2.2.10 Analysis Requirements

2.2.10.1 Sensitivity

The sensitivity of an ATD system is dependent upon the area of the detector that is counted for alpha tracks. Table 2-1 illustrates this dependence of precision on the number of net tracks counted. The organization performing the measurements should verify that the area or number of net tracks counted by the ATD processor provides an adequate sensitivity at the radon concentration at which a decision is made. In the past, the EPA and the Centers for Disease Control have used 4 pCi/l as a decision point, and it is recommended that enough net tracks be counted to allow for a reasonable sensitivity at this concentration. As can be seen from Table 2-1, if few net tracks are counted, a very poor precision is obtained. Thus, it is critical that the organization performing the measurements with an ATD arranges for an adequate sensitivity.

Table 2-1

DEPENDENCE OF PRECISION ON NUMBER OF NET TRACKS COUNTED

| Number of Net Tracks Counted | 2 Sigma Error (%)(a) |
|---|---|
| 4 | 100 |
| 6 | 82 |
| 10 | 63 |
| 15 | 52 |
| 20 | 45 |
| 50 | 28 |
| 75 | 23 |
| 100 | 20 |

(a) This is the minimum error for the number of net tracks indicated; the absolute error is dependent on the actual number of background tracks counted.

2.2.10.2 Precision

The coefficient of variation should be monitored using the results of the duplicate detectors described in section 2.2.11.2 of this protocol, rather than a precision quoted by the manufacturer.

2.2.11 Quality Assurance

The quality assurance program for measurements with ATDs involves three separate parts: (1) calibration or accuracy testing, (2) duplicate detectors as a test of the precision, and (3) control detectors to check for exposure during shipment or storage.

The EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA Office of Radiation Programs Quality Assurance Officer by calling (FTS or 703) 557-7380, or call 800-334-8571, extension 7131, for further information about this program.

2.2.11.1 Calibration

Conversion Factor Determination

Determination of a calibration factor requires exposure of ATDs to a known radon concentration in a radon exposure chamber. These calibration exposures are to be used to obtain or verify the conversion factor between net tracks per unit area and radon concentration. The following guidance is provided to the supplier of alpha-track services as minimum requirements in determining the calibration factor.

- ATDs should be exposed in a radon chamber at several different radon concentrations or exposure levels similar to those found in the tested houses (a minimum of three).
- A minimum of 10 detectors should be exposed at each level.
- The period of exposure should be sufficient to allow the ATD to achieve equilibrium with the chamber atmosphere.
- A calibration factor should be determined for each batch of detector material received from the material supplier.

Blind Calibration Detectors

Both suppliers of alpha-track services and large users of these services should submit ATDs with known radon exposures for analysis on a regular schedule. Blind calibration detectors should

be labelled in the same manner as field detectors to assure identical processing. The number of blind calibration detectors submitted for analysis should be a few percent of the total number of detectors analyzed.

The concentrations that the detectors are exposed to during calibration should be in the same range that the field detectors are exposed to. For users who accumulate detectors over a period of time and submit relatively large groups of detectors for analysis, the preferred approach is to include blind calibration detectors with each group of detectors analyzed. The results of the calibration detector analysis should be monitored for any significant deviation from the known concentration to which they were exposed.

2.2.11.2 Duplicates

The organization performing the measurements should place duplicate detectors in enough houses to test the precision of the measurement. The number of duplicate detectors deployed should be either 10 percent of the number of detectors deployed each month or 50, whichever is smaller. The pair of detectors should be treated identically in every respect. They should be shipped, stored, opened, installed, removed, and processed together and not identified as duplicates to the processing laboratory. Data from duplicate detectors should be evaluated using the procedures recommended for internal quality control programs for replicate analysis (Ro65; EPA80). The method should achieve a coefficient of variation of 20 percent (1 sigma) or less. Consistent failure in duplicate agreement indicates an error in the measurement process that should be investigated.

2.2.11.3 Control Detectors

Control detectors should include a minimum of five percent of the detectors that are deployed every month, or 25, whichever is smaller. They should be selected and stored by the organization performing the measurements. The control detectors should be stored in sealed containers with radon concentrations of less than about 0.5 pCi/l. These detectors should be handled and shipped using the same procedures that are used for the other detectors in the exposure group with the exception of the storage during the field measurements. The results of the control detector analyses should be monitored. If the results approach a significant fraction of the results from the field detectors, the control detector results can be subtracted from the results of the other detectors in the exposure group. The cause for the high exposures can then be investigated. A significant result from the control detector analyses may indicate a problem in the shipping, storage, or processing of the detectors.

## 2.3 PROTOCOL FOR USING CHARCOAL CANISTERS TO MEASURE INDOOR RADON CONCENTRATIONS

### 2.3.1 Purpose

This protocol provides guidance for using a charcoal canister to obtain accurate and reproducible measurements of indoor radon concentrations. Following the protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce measurements of radon concentration representative of standardized, closed-house conditions. Such measurements of closed-house concentrations have a smaller variability and are more reproducible than measurements made when the house conditions are not controlled.

### 2.3.2 Scope

This protocol covers, in general terms, the equipment, procedures, and quality control objectives to be used in performing the measurements. This document provides guidelines to be adopted into standard operating procedures. More information about of the procedures may be obtained from the U.S. EPA Office of Radiation Programs (ANR-460), 401 M Street, S.W., Washington, D.C., 20460.

### 2.3.3 Method

Charcoal canisters are passive devices requiring no power to function. They are integrating detectors and can be used to determine the average radon concentration in the device's location during the measurement period.

The charcoal canister measurement technique is described in detail by Cohen and George (Co83 and Ge84). The charcoal canister now used by several groups consists of a circular, 6-to-10 centimeters diameter container approximately 2.5 centimeters deep filled with 25 to 100 grams of activated charcoal. One side of the container is fitted with a screen that keeps the charcoal in but allows air to diffuse into the charcoal. When the canister is prepared by the supplier it is sealed with a cover until it is ready to be deployed.

To initiate the measurement, the cover is removed to allow air to diffuse into the charcoal bed. Radon in the air will be adsorbed onto the charcoal and will subsequently decay, depositing decay products in the charcoal. At the end of a measurement period, the canister is resealed using the cover and is returned to a laboratory for analysis.

At the laboratory, the canisters are analyzed for radon decay products by placing the charcoal, still in its canister, directly on a gamma detector. Gamma rays of energies between 0.25 and 0.61 Mev are counted. It is necessary to make a correction to

account for the reduced sensitivity of the charcoal due to adsorbed water. This may be done by weighing each canister when it is prepared and then reweighing it when it is returned to the laboratory for analysis. Any weight increase is attributed to water adsorbed on the charcoal. The weight of water gained is correlated to a correction factor that should be empirically derived using a method discussed by George (Ge84). This correction factor is used to correct the analytical results.

This correction is not needed if the charcoal canister configuration is modified to significantly reduce the adsorption of water and the user has experimentally demonstrated that, over a wide range of humidities, there is a negligible change in the collection efficiency of the charcoal.

The charcoal canister system can be calibrated by analyzing canisters exposed to known concentrations of radon in a calibration facility.

### 2.3.4 Equipment

Charcoal canisters made specifically for ambient radon monitoring can be obtained from commercial suppliers or can be manufactured using readily available components. Some canisters designed for use in respirators or in active air sampling may be adapted for use in ambient radon monitoring, as described by Cohen and George (Co83; Ge84).

The following equipment will be required to initiate charcoal canister monitoring in each house:

- Charcoal canister(s) sealed with protective cover.
- Instruction sheet for occupant, and a shipping container and, if sent by mail, a prepaid mailing label for returning canister(s) to the analytical laboratory.

Laboratory analysis of the exposed canisters is performed using a sodium iodide gamma scintillation detector to count the gamma rays emitted by the radon decay products on the charcoal. The detector may be used in conjunction with a multichannel gamma spectrometer or with a single-channel analyzer with the window set to cover the appropriate gamma energy window.

### 2.3.5 Predeployment Considerations

The measurement should not be made if the occupant is planning remodeling, changes in the heating, ventilating and air conditioning (HVAC) system, or other modifications that may influence the radon concentration during the measurement period.

The canister should not be deployed if the occupant's schedule prohibits terminating the measurement at the time selected for closing the canister and returning it to the laboratory.

### 2.3.6 Measurement Criteria

The following conditions should exist during a measurement period to ensure that the conditions are as standardized as possible.

- To a reasonable extent, the house should be closed, with all windows and external doors shut (except for normal extrance and exit) for at least 12 hours prior to and during the sampling period. Normal entrance and exit includes a brief opening and closing of a door, but an external door should not be left open for a period of more than a few minutes. These conditions are expected to exist as normal living conditions during the winter in northern climates. For this reason and other reasons discussed in section 1.2.1, measurements should be made during the winter periods whenever possible.

- Internal-external air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operated for at least 12 hours prior to and during the measurement period. This condition can be most conveniently satisfied if the measurement is begun in the morning, after the occupant has been instructed to keep the windows closed during the night and not to open them until the measurement is completed. Air conditioning systems that recycle interior air may be operated. The closed-house conditions must be more rigorously verified and maintained, however, when they are not the normal living conditions.

- The measurement should not be conducted if severe storms with high winds are predicted during the measurement period. Weather predictions available on local news stations will provide sufficient information to determine if this condition is satisfied.

### 2.3.7 Deployment

#### 2.3.7.1 Timely Deployment

Charcoal canisters should be deployed into houses as soon as possible after they are prepared. Until they are deployed, they should remain tightly sealed to maintain maximum sensitivity and low background.

2.3.7.2 Location Selection

The following criteria should be applied to select the location of a canister within a room.

- o A position must be selected where the canister will not be disturbed during the measurement period.
- o The canister should not be placed near drafts caused by HVAC vents, windows, and doors. Avoid locations near excessive heat, such as fireplaces or in direct, strong sunlight.
- o The canister should be placed flat on a shelf or table at least 50 centimeters (20 inches) above floor level and with the detector's top face at least 10 centimeters (4 inches) from other objects.
- o The canister should not be placed close to the outside walls of the house.

The protective cover should be removed from the canister to begin the sampling period. The cover must be saved to reseal the canister at the end of the measurement. Inspect the canister to see that it has not been damaged during handling and shipping. It should be intact, with no charcoal leaking. Place the canister with the open side up toward the air. Nothing should impede air flow around the canister.

Accurately fill in the information called for on the data form on the canister. Record the canister serial number in a log book along with a description of the location in the house where the canister was placed. If the canister is relocated during the measurement period the new location should be noted in the log book.

2.3.8 Retrieval of Detectors

The canisters should be deployed for a 3 to 7 day measurement period. If the occupant is terminating the sampling, the instructions given to the occupant should tell the occupant when to terminate the sampling period and should indicate that a deviation from the schedule by up to 6 hours is acceptable so long as the time of termination is documented on the canister. In addition, the occupant should also be instructed to send the canister to the laboratory as soon as possible, preferably the day of or the day following termination.

At the end of the monitoring period, the canister should be inspected for any deviation from the conditions described in the log book at the time of deployment. Any changes should be noted. The canister should be resealed using the original protective cover.

After the canister is retrieved, it must be returned to the laboratory as soon as possible for analysis. The canister should not be analyzed before 3 hours after the end of sampling to allow for ingrowth of decay products.

### 2.3.9 Analysis Requirements

Canisters should be analyzed in the laboratory as soon as possible following removal from the houses. The maximum allowable delay time between the end of sampling and analysis will vary with the background experienced in each laboratory and should be evaluated, especially if sensitivity is of prime consideration. Corrections for the Rn-222 decay during sampling, during the interval between sampling and counting, and during counting should be made. The canister should be weighed, and, if necessary, a correction should be applied for the increase in weight due to moisture adsorbed. A description of the procedure used to derive the moisture correction factor is provided by George (Ge84).

#### 2.3.9.1 Sensitivity

For a 3 to 7 day exposure period, the lower level of detection (LLD) (delay-time corrected) should be 1 pCi/l or less. This can be normally achieved with a counting time of up to 30 minutes. This LLD should be calculated using the results of the charcoal background determination that is described in section 2.3.11.3 of this protocol.

#### 2.3.9.2 Precision

The coefficient of variation should not exceed 10 percent at radon concentrations of 4 pCi/l or greater. This precision should be monitored using the results of the duplicate canister analyses described in section 2.3.11.2 of this protocol.

### 2.3.10 Documentation

It is important that enough information about the measurement be recorded in a permanent log so that data interpretations and comparisons can be made. The information includes:

- The date and start and stop time of the measurement.
- Whether standardized conditions, as previously specified, are satisfied.
- Exact location of the instrument, on a diagram of the room and house, if possible.

- Other easily gathered information that may be useful, such as the type of house, type of heating system, existence of crawl space, occupants smoking habits, and operation of humidifiers, air filters, electrostatic precipitators, or clothes dryers.

### 2.3.11 Quality Assurance

The quality assurance program for charcoal canisters includes three parts: (1) calibration canisters, (2) duplicate canisters, and (3) controls. The purpose of this program is to identify the accuracy and precision of the measurements and to assure that the measurements are not influenced by exposure from sources outside the intended structure.

The EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA Office of Radiation Programs Quality Assurance Officer by calling (FTS or 703) 557-7380, or call 800-334-8571, extension 7131, for further information about this program.

#### 2.3.11.1 Calibration

##### Determination of Calibration Factors

Determination of calibration factors for charcoal canisters requires exposure of canisters to known concentrations of radon-222 in a radon exposure chamber. The calibration factors are dependent upon both the exposure time and the amount of water adsorbed by the canister during exposure. These calibration factors should be determined using the procedures described by George (Ge84). Calibration factors should be determined for each charcoal canister system (container type and amount of charcoal).

##### Blind Calibration Canisters

Both suppliers of charcoal canister services and large users of these services should submit charcoal canisters with known radon exposures for analysis on a regular schedule. Blind calibration canisters should be labelled in the same manner as the field canisters to assure identical processing. The number of blind calibration canisters submitted for analysis should be a few percent of the total number of canisters analyzed. The results of the calibration canister analysis should be monitored for any significant deviation from the known concentration to which they were exposed.

### 2.3.11.2 Duplicates

Duplicate canisters should be placed in enough houses to monitor the precision of the instrument. This will usually be approximately 10 percent of the houses to be tested each month, or 50, whichever is smaller. The duplicate canisters should be shipped, stored, exposed and analyzed under the same conditions. Data from duplicate canisters should be evaluated using the procedures recommended for internal quality control programs for replicate analysis (Ro65, EPA80). The method should achieve a coefficient of variation of 10 percent (1 sigma) or less. Consistent failure in duplicate agreement indicates an error in the measurement process that should be investigated.

### 2.3.11.3 Control Canisters

#### Charcoal Background

A background gamma count can be obtained for an entire batch of charcoal by counting several canisters from each batch of charcoal. This is the background that should be subtracted from the field canister results.

#### Background Exposure Monitoring

In addition, a minimum of 5 percent of the detectors that are deployed every month, or 25, whichever is smaller, should be set aside from each shipment. They should be kept in a low radon (less than 0.5 pCi/1) environment and sent back with one shipment each month for analysis. These canisters measure the background exposure due to radon that may accumulate during shipment. The results from these field canisters should be monitored; and if the results approach a significant fraction of the results from the field detectors, the control detector results can be subtracted from results of the other detectors in the exposure group. The cause for the elevated readings should then be investigated.

## 2.4 PROTOCOL FOR THE DETERMINATION OF INDOOR RADON CONCENTRATION BY GRAB SAMPLING

### 2.4.1 Purpose

This protocol provides guidance for using the grab sampling technique to provide accurate and reproducible measurements of indoor radon concentrations. Following the protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce measurements of radon concentration representative of standardized, closed-house conditions. Such measurements of closed-house concentrations have a smaller variability and are more reproducible than measurements made when the house conditions are not controlled.

### 2.4.2 Scope

This protocol covers, in general terms, the equipment, procedures, and quality control objectives to be used when performing measurements. This document provides guidelines to be incorporated into standard operating procedures used by a State or other laboratory. More information about the procedures may be obtained from the U.S. EPA Office of Radiation Programs (ANR-460), 401 M Street, S.W., Washington, D.C., 20460.

### 2.4.3 Method

In this grab sampling method, a sample of air is drawn into and sealed in a flask or cell that has a zinc sulfide phosphor coating on its interior surfaces. One surface of the cell is fitted with a clear window that is put in contact with a photomultiplier tube to count light pulses (scintillations) resulting from alpha disintegrations from the sample interacting with the zinc sulfide coating. The number of pulses is proportional to the radon concentration in the cell.

The cell is counted about 4 hours after filling to allow the short-lived RDPs to reach equilibrium with the radon. Correction factors (see Appendix A) are applied to the counting results to compensate for decay during the time between collection and counting and to account for decay during counting.

### 2.4.4 Equipment

The equipment needed to obtain the sampling includes:

- A scintillation cell or cells to be filled at the site.
- A pump to flow air through the cell or to evacuate the cell (depending on the valve arrangement on the cell in use).

- A clock to measure time from collection to counting.
- A filter and filter holder to attach to the air inlet valve of cell.

The equipment required for cell counting includes:

- A photomultiplier tube and high-voltage assembly in a light-tight chamber.
- A scaler-timer for registering pulses from photomultiplier the tube assembly and timing the counting interval.
- A National Bureau of Standards (NBS)-traceable alpha check source and scintillation disc.
- A calibration cell.
- A vacuum pump and cell flushing apparatus.
- Aged air or nitrogen for flushing counting cells.

### 2.4.5 Premeasurement Considerations

Prior to collection of the sample, proper operation of the counting equipment must be verified, and counter efficiency and background must be determined. In addition, a background for each cell should be determined prior to sampling. This may be done using the procedures described in Appendix A.

For highly accurate measurements, it is necessary to standardize cell pressure prior to counting, because the path lengths of alpha particles are a function of air density. For example, a cell calibrated at sea level and used to count a sample collected at Grand Junction, Colorado (1370 meters ASL) would overestimate the radon activity of the sample by about 9 percent (Ge83). This error probably approaches the maximum that would be encountered; therefore, it may not be necessary to make this correction if this error can be tolerated. Correction procedures are given elsewhere (Ge83).

### 2.4.6 Measurement Criteria

The following conditions should exist prior to and during the sampling to ensure that the conditions are as standardized as possible.

- The sampling should be made under closed-house conditions. To a reasonable extent, external doors and windows should be closed for 12 hours prior to the measurement (except for normal entrance and exit).

Normal entrance and exit includes a brief opening and closing of a door, but an external door should not be left open for more than a few minutes. No windows or doors should be open during the sampling period. These conditions are expected to exist as normal living conditions during the winter in northern climates. For this reason and other reasons discussed in section 1.2.1, measurements should be conducted during winter whenever possible.

- Internal-external air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operated for at least 12 hours prior to and during the sampling.

- In southern climates or when measurements must be made during a warm season, the closed-house conditions will be satisfied by meeting the preceding criteria. In other seasons and climates, this condition can be most conveniently satisfied if the sampling is done after the occupant has been instructed to keep the windows closed and all internal-external ventilation systems off during the night until after the measurement is made. Air conditioning systems that recycle interior air may be operated prior to the measurement, if necessary, but not during the measurement. The closed-house conditions must be more rigorously verified and maintained, however, when they are not the normal living conditions.

- The sampling should not be conducted if severe storms with high winds have occurred in the previous 12 hours or are present at the sampling time.

### 2.4.7 Documentation

It is important that enough information about the measurement is recorded in a permanent log so that data interpretations and comparisons can be made. This will include:

- The time and date of the start and end of the measurement,

- Whether standardized conditions, as previously specified, are satisfied,

- Exact location of the measurement, on a diagram, of the room and house, if possible,

- Other easily gathered information that may be useful, such as the type of house, type of heating system, existence of crawl space, occupants smoking habits, and operation of humidifiers, air filters, electrostatic precipitators, or clothes dryers.

### 2.4.8 Sampling Operations

#### 2.4.8.1 Location in Room

The sample should be collected in an area away from drafts. The sample should not be collected near heating, ventilation, or air conditioning (HVAC) vents, windows and doors, clothes dryer or stove vents, and fireplaces. The sample should not be taken near the outside walls of the house. If possible, entrance into a basement room for sampling should be made through an interior stairway rather than an exterior door, to reduce the ventilation caused by the opening of the door.

#### 2.4.8.2 Sampling

All air samples drawn into cells must be filtered to remove airborne radioactive particulates including RDPs. This prevents contamination of the cells and helps maintain low cell backgrounds. Filters may be reused many times as long as they remain undamaged.

To collect a sample using a single-valve cell (Lucas type), the cell is evacuated to at least 25 inches of mercury, the filter is attached to the cell, and the valve is opened allowing the cell to fill with air. Allow at least 10 seconds for the cell to completely fill. To assure good vacuum at the time of sampling, the cell may be evacuated using a small hand operated pump in the room being sampled. It is good practice to evacuate the cell at least five times, allowing it to fill completely with room air each time. Make sure the air to be sampled flows through the filter each time. If it can be demonstrated that the cells and valves do not leak, it is acceptable to evacuate the cells in the laboratory and simply attach the filter and open the valve in the house to collect a sample.

To sample using the double-valve, flowthrough type cell, attach the filter to the inlet valve and a suitable vacuum pump to the other valve. The pump may be motor driven or hand operated. Open both valves and operate the pump to flow at least 10 complete air exchanges through the cell. Stop the pump and close both valves.

Record all pertinent sampling information after taking the sample. Include the date and time, location, cell number, name of person collecting the sample, and any other significant conditions within the house or notes on the weather conditions. Store the cells for return to the counting location carefully so that the samples will not be lost due to cell breakage or valves being opened.

### 2.4.9 Counting and Calculations

Cells should not be counted for at least four hours following the time of collection. Background and check sources should be counted as described in Appendix A. The cell to be

counted is placed on the photomultiplier tube, the cover placed over the cell, and the system allowed to dark adapt. The cell may then be counted for a sufficient period to collect an adequate number of counts for good counting statistics in relation to the system background counts.

The results in picocuries per liter of radon in air are calculated using the formulas and tables in Appendix A, which includes a sample calculation.

### 2.4.10 Cell Flushing and Storage

After the cells have been counted and data are satisfactorily recorded, the cells must be flushed with aged air or nitrogen to remove the sample. Flowthrough cells are flushed with at least ten volume exchanges at a flow of about 2 liters per minute. Cells with single valves are evacuated and refilled with aged air or nitrogen at least five times. The cells are left filled with the aged air or nitrogen and allowed to sit overnight before being counted for background. If an acceptable background is obtained, the cell is ready for reuse.

### 2.4.11 Results

#### 2.4.11.1 Sensitivity

The sensitivity of the method is dependent on the volume of the cell being used. However, sensitivities of 0.1 picocuries per liter are achievable (Ge80b, Ge83).

#### 2.4.11.2 Precision

The coefficient of variation for duplicate samples should not exceed 30 percent at radon concentrations of 1 picocurie per liter or more. This precision should be monitored using the results of duplicate measurements described in Section 2.4.12.2 of this protocol. Sources of error in the procedure may result from improper cell calibration, leaking cells, and improperly calibrated counting equipment.

### 2.4.12 Quality Assurance

The quality assurance program for radon concentration measurements using grab sampling includes calibration and duplicate measurements.

The EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA

Office of Radiation Programs Quality Assurance Officer by calling (FTS or 703) 557-7380, or call 800-334-8571, extension 7131, for further information about this program.

2.4.12.1 Calibration

The counting system consisting of the scaler, detector, and high-voltage supply must be calibrated. The correct high voltage is determined via a plateau (incrementing the high voltage and plotting the resultant counts). This procedure is described elsewhere (Ge83). Each counting system should be calibrated before being put into service, after any repair, or at least once per year. Also, a check source or calibration cell should be counted in each counter system each day to demonstrate proper operation prior to counting any samples.

An accurate calibration factor must be obtained for each counting cell. This is done by filling each cell with radon of a known concentration and counting the cell to determine the conversion factor of counts per minute per picocurie. The known concentration of radon may be obtained from a radon calibration chamber or estimated from a bubbler tube containing a known concentration of radium. These calibration procedures are discussed elsewhere in more detail (Ge76; Ge83; Lu57; Be75).

At least once a year, grab measurements should be made in a known radon environment in a radon calibration chamber to verify the conversion factor.

2.4.12.2 Duplicates

Duplicate samples should be collected with sufficient frequency to test the precision of the procedure. This number should be at least 10 percent of the total radon grab samples collected. Care should be taken to ensure that the samples are duplicates to the greatest extent possible. Duplicate cells should be filled close to each other and away from drafts. Data from duplicate samples should be evaluated using the procedures recommended for internal quality control programs for replicate samples (Ro65, EPA80). The method should achieve a coefficient of variation of 30 percent (1 sigma) or less. Consistent failure in duplicate agreement indicates an error in the measurement process that should be investigated.

## Section 3: RADON DECAY PRODUCT MEASUREMENT PROTOCOLS

### 3.1 PROTOCOL FOR USING A CONTINUOUS WORKING LEVEL MONITOR TO MEASURE INDOOR RADON DECAY PRODUCT CONCENTRATION

#### 3.1.1 Purpose

This protocol provides guidance for using a continuous working level monitor (CWLM) to obtain accurate and reproducible measurements of indoor radon decay product concentrations. Following the protocol will help assure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce measurements of radon decay product (RDP) concentrations representative of standardized closed-house conditions. Such measurements of closed-house concentrations have a smaller variability and are more reproducible than measurements made when the house conditions are not controlled.

#### 3.1.2 Scope

This protocol covers, in general terms, the sample collection and analysis method, the equipment needed, and the quality control objectives of measurements made with a CWLM. It is not meant to replace an instrument manual, but provides guidelines that should be incorporated into standard operating procedures. More information about the procedures may be obtained from the U.S. EPA Office of Radiation Programs (ANR-460), 401 M Street, S.W., Washington, D.C., 20460.

#### 3.1.3 Method

A CWLM samples the ambient air by filtering airborne particles as the air is drawn through a filter cartridge at a low flow rate of about 0.1 to 1 liter per minute. An alpha detector such as a diffused-junction or surface-barrier detector counts the alpha particles produced by the RDP as they decay on the filter. The detector is normally set to detect alpha particles with energies between 2 and 8 MeV. The alpha particles emitted from the radon decay products Po-218 and Po-214 are the significant contributors to the events that are measured by the detector. The event count is directly proportional to the number of alpha particles emitted by the RDP on the filter. The unit typically contains a microprocessor that stores the number of counts and elapsed time. The unit can be set to record the total counts registered over specified time periods. The unit must be calibrated in a calibration facility to convert count rate to working level (WL) values. This may be done initially by the manufacturer and should be done periodically thereafter by the operator.



Preceding page blank

### 3.1.4. Equipment

In addition to the CWLM, equipment needed includes replacement filters, a readout or programming device (if not part of the CWLM), an alpha-emitting check source, and an air-flow rate meter.

### 3.1.5 Predeployment Testing

The CWLM should be carefully tested before and after each measurement to:

- Verify that a new filter has been installed and the input parameters and clock are set properly,
- Measure the detector's efficiency with a check source such as Am-241 or Th-230 and ascertain that it compares well with the technical specifications for the unit,
- Verify the operation of the pump.

After every 100 hours of operation, the unit should be checked to measure the background count rate using the procedures that may be identified in the operating manual for the instrument.

In addition, participation in a laboratory intercomparison program at least semiannually will verify that the conversion factor used in the microprocessor is accurate. This is done by comparing the unit's response to a known RDP concentration. At this time, the correct operation of the pump should also be verified by measuring the flow rate.

### 3.1.6 Measurement Criteria

The following house conditions should exist prior to and during a measurement to standarize the measurement conditions as much as possible.

- The measurement should be made under closed-house conditions. To the extent reasonable, windows and external doors should be closed (except for normal entrance and exit) for 12 hours prior to and during the measurement period. Normal entrance and exit includes an opening and closing of a door, but an external door should not be left open for more than a few minutes. These conditions are expected to exist as normal living conditions during the winter in northern climates. For this reason and other reasons discussed in section 1.2.1, measurements should be made during winter whenever possible.

- Internal-external air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operating during the measurement and for at least 12 hours before the measurement is initiated.

- In southern climates or when the measurements must be made during a warm season, the standardized closed-house conditions are satisfied by meeting the preceding criteria. These criteria can be most conveniently satisfied if the measurement is begun in the morning, after the occupant has been instructed to keep the windows closed during the night and not to open them until the measurement has been completed. Air conditioning systems that recycle interior air may be operated. The closed-house conditions must be more rigorously verified and maintained, however, when they are not the normal living conditions.

- The measurement should not be conducted if severe storms with high winds are predicted during the measurement period. Weather predictions available on local news stations will provide sufficient information to determine whether this criterion is satisfied.

### 3.1.7 Deployment and Operation

#### 3.1.7.1 Location Selection

The following criteria should be applied to select the location of the CWLM within a room.

- The measurement should not be taken near drafts caused by heating, ventilating and air conditioning (HVAC) vents, doors, windows, and fireplaces.

- The measurement location should not be close to the outside walls of the house.

- The unit should be placed on a table or stool so that the air intake is at least 50 centimeters (20 inches) from the floor.

#### 3.1.7.2 Operation

The CWLM should be programmed to run continuously, recording the hourly integrated WL measured and, when possible, the total integrated average WL. The sampling period should not be less 24 hours for most purposes. The longer the operating time, the smaller the uncertainty associated with the measurement result. The integrated average WL over the measurement period should be used as the measurement result.

3.1.7.3 Documentation

It is important that the operator of the CWLM records enough information about the measurement in a permanent log so that data interpretations and comparisons can be made. This will include:

- The time and date of the start and end of the measurement,
- Whether standardized conditions, as specified, are satisfied,
- Exact location of the instrument, on a diagram if possible.
- Other easily gathered information that may be useful, such as the type of house, type of heating system, existence of crawl space, occupants smoking habits, and operation of humidifiers, air filters or electrostatic precipitators, and clothes dryers.

3.1.8 Quality Assurance

The elements of a quality assurance program for the CWLM are:

- Calibration in a radon decay product exposure calibration chamber at least every 6 months, or after instrument repair or modification, and
- Checks using an Am-241 or Th-230 similar-energy alpha check source (before and after each measurement),
- Background count-rate checks (after each 100 hours of operation).

The EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA Office of Radiation Programs Quality Assurance Officer by calling (FTS or 703) 557-7380, or call 800-334-8571, extension 7131, for further information about this program.

## 3.2 PROTOCOL FOR USING RADON PROGENY INTEGRATING SAMPLING UNITS (RPISU) TO MEASURE INDOOR RADON DECAY PRODUCT CONCENTRATIONS

### 3.2.1 Purpose

This protocol provides guidance for using a RPISU to produce accurate and reproducible measurements of indoor radon decay product concentrations. Following the procedure will help ensure uniformity in measurement programs and allow valid intercomparison of results. Measurements made in accordance with this protocol will produce measurements of radon decay product concentrations (RDP) representative of standardized closed-house conditions. Such measurements of closed-house concentrations have a smaller variability and are more reproducible than measurements made when the house conditions are not controlled.

### 3.2.2 Scope

This protocol covers, in general terms, the equipment, procedures, analysis, and quality control objectives for measurements made with RPISUs. It is not meant to replace an instrument manual, but provides guidelines to be adopted into standard operating procedures. More information about the procedures may be obtained from the U.S. EPA Office of Radiation Programs (ANR-460), 401 M Street, S.W., Washington, D.C., 20460.

### 3.2.3 Method

The RPISU contains an air sampling pump that draws a continuous flow of air through a detector assembly. The detector assembly includes a filter and at least two thermoluminescent dosimeters (TLDs). One TLD measures the radiation emitted from radon decay products collected on the filter, and the other TLD is used for background gamma correction. The pump and detector assembly are operated inside the structure for 3 to 7 days.

Analysis of the detector TLDs is performed in a laboratory utilizing a thermoluminescent dosimeter reader. Interpretation of the results of this measurement requires a calibration for the detector and an analysis system based on exposures to known concentrations of radon decay products.

### 3.2.4 Equipment

The RPISU sampling system includes the sampling pump and the detector assembly. Analysis requires a thermoluminescent dosimeter reader.

#### 3.2.4.1 Sampling Pump

The air sampling pump must be capable of moving air at a flow rate ranging from 0.1 to 4 lpm through the detector assembly.

The pump must be suitably quiet to allow operation in an occupied residence without creating a major annoyance. The pump should also include a running-time meter. High-flow-rate pumps require an automatic shut-down system if the flow rate is reduced to less than an adequate rate or if the pump overheats. A calibrated flow meter to measure the flow rate through the detector must also be available.

3.2.4.2 Detector Assembly

The detector assembly includes a holder suitable to contain the filter and TLDs that will allow entry of air to the filter. One TLD is placed directly adjacent to the face of the filter to detect alpha radiation coming from the particles collected on the filter. The other TLD is placed behind a stainless steel shield to measure the gamma and beta radiation received during exposure, storage, and shipment. The filter for the detector should present a uniform surface with pore sizes no larger than 0.8 microns.

3.2.4.3 Thermoluminescent Dosimeter Reader

The TLD reader is an instrument that heats the TLDs at a uniform and reproducible rate and simultaneously measures the light emitted by the thermoluminescent material. The readout process is carefully controlled, with the detector purged with nitrogen to prevent spurious emissions. The TLD reader should be periodically tested using dosimeters exposed to a known level of alpha or gamma radiation prior to analyzing the RPISU dosimeters. TLDs are prepared for reuse by cleaning and annealing at prescribed temperatures in an oven.

3.2.5 Predeployment Considerations

Prior to installation in the house, the pump should be checked to assure that it is operable and capable of maintaining an adequate flow through the detector assembly. Extra detector assemblies should be available during deployment in case a problem is encountered.

Arrangements should be made with the occupant of the house to assure that entry to the house can be made at the time of delivery and to determine availability of a suitable electrical outlet near the sampling area in the selected room.

3.2.6 Measurement Criteria

The following house conditions should exist during a measurement period to ensure that the conditions are as standardized as possible.

- To a reasonable extent, the house should be closed, with all windows and external doors shut (except for normal entrance and exit) for 12 hours prior to and during the measurement period. Normal entrance and exit includes a

brief opening and closing of a door, but an external door should not be left open for more than a few minutes. These conditions are expected to exist as normal living conditions during the winter in northern climates. For this reason and other reasons discussed in section 1.2.1, measurements should be made during the winter whenever possible.

- Internal-external air exchange systems (other than a furnace), such as high-volume attic and window fans, should not be operated for at least 12 hours prior to and during the measurement.

- In southern climates or when measurements must be made during a warm season, the closed-house conditions are satisfied by meeting the preceding criteria. This condition can be most conveniently satisfied by beginning a sampling period in the morning after the occupants have been instructed to keep the windows closed and not to open them until the measurement is completed. Air conditioning systems that recycle interior air may be operated. The closed-house conditions must be more rigorously verified and maintained, however, when they are not the normal living conditions.

- The measurement should not be conducted if severe storms with high winds are predicted for the measurement period. Weather predictions available on local news stations will provide sufficient information to determine if this criterion is satisfied.

### 3.2.7 Deployment and Operation

Install the RPISU and check the air flow rate with a calibrated flow meter. Record the location, date, starting time, running time meter reading, and flow rate on the detector assembly envelope and in a log. Observe the RPISU for a few minutes after starting, to assure continued operation; also inform the occupants about the RPISU and request that they report any problems or pump shut down. The occupant should be aware of the length of time the RPISU will be operated, and an appointment should be arranged to retrieve the unit. The criteria for the standardized measurement conditions should be repeated to the occupants.

The sampling period should be at least 72 hours. A longer operating time decreases the uncertainty associated with the measurement result.

3.2.7.1 Location Selection

The following criteria should be used to select the location of the RPISU within a room:

- The RPISU should not be placed close to the outside walls of the house.
- The air intake (sampling head) should be placed at least 20 centimeters (8 inches) from surfaces that may obstruct flow.
- The RPISU should not be placed near drafts caused by HVAC vents, windows, fireplaces, or doors.

3.2.8 Retrieval

Prior to pump shut-down the flow rate should be measured with a calibrated flow meter and the unit should be observed briefly to assure that it is operating properly. If the sampling pump is not operating, attempt to restart it even briefly to perform flow measurements. Return the detector assembly to its envelope and record the date, time, running time meter reading, and flow rate both on the detector assembly envelope and in a log book. Also, record any other observed conditions that might affect the measurement. Remove the RPISU sampling pump and any ancillary equipment.

3.2.9 Analysis

Analysis of the RPISU detector assembly should be performed in a laboratory under controlled conditions. The analysis should be delayed for at least 3 hours after the sampling is completed to allow for decay of radon decay products collected on the filter.

Prior to analysis, the TLDs should be removed from the detector assembly, and the filter should be checked for observable holes or leakage. The TLD identification numbers should be checked against the recorded numbers, and, if specified by the TLD supplier, the TLDs should be cleaned using the manufacturers recommended procedures.

The TLDs are then analyzed in the TLD reader using established procedures. Note that the side of the TLD that received the exposure from the filter should be placed adjacent to the photomultiplier tube.

Dosimeter numbers (if available) and readings for both the alpha TLD and background (gamma/beta) TLD should be recorded as well as all other pertinent information on the detector assembly envelope or data sheet.

### 3.2.10 Documentation

It is important that enough information about the measurement is recorded in a permanent log so that data interpretations and comparisons can be made. This will include:

- The time and date of the start and end of the measurement,
- Whether standardized conditions, as previously specified, are satisfied,
- Exact location of the instrument, on a diagram, of the room and house, if possible,
- Other easily gathered information that may be useful, such as the type of house, type of heating system, existence of crawl space, occupants smoking habits, and operation of humidifiers, air filters, electrostatic precipitators, or clothes dryers.

### 3.2.11 Quality Assurance

The quality assurance program for measurements of radon decay product concentrations in terms of working levels comprises three elements: (1) calibration or accuracy testing, (2) duplicate measurements and (3) control dosimeters to measure exposure during shipment and storage.

The U.S. EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA Office of Radiation Programs Quality Assurance Officer by calling (FTS or 703) 557-7380, or call 800-334-8571, extension 7131, for further information about this program.

#### 3.2.11.1 Calibration

Calibration of RPISU dosimeters requires exposure in a controlled radon-exposure chamber where the radon decay product concentration is known during the exposure period. The detector assembly must be exposed in the chamber using a flow rate similar to the normal operating flow rate for the RPISU sampling pumps. The environmental conditions in the chamber during all exposures should be similar to those that are found in the tested houses. Calibration should include exposure of a minimum of four detectors exposed at different RDP concentrations representative of the range found in field measurements. The relationship of thermoluminescent dosimeter reader units to working level for a given sample volume and the

standard error associated with this measurement should be determined. Calibration of the RPISUs also includes testing of air-flow meters to ensure accuracy of the flow rate measurement.

After the initial calibration, periodic processing of exposed detectors should be done to assure that the detection system has not changed.

3.2.11.2 Duplicates

The organization performing the measurements should make duplicate measurements with RPISUs in enough houses to test the precision of the measurement. This number should be at least 10 percent of the houses tested. The two RPISUs should be located in the same area in the house, and all handling and analysis of the detectors should be identical. Data from duplicate detectors should be evaluated using the procedures recommended for internal quality control programs for replicate analysis (Ro65, EPA80). The method should achieve a coefficient of variation of 10 percent (1 sigma) or less. Consistent failure in duplicate agreement indicates an error in the measurement process that should be investigated.

11.3 Control Dosimeters

Control dosimeters for RPISUs are included in each detector assembly. The purpose of these control dosimeters is to identify any exposure from sources of radiation other than the radon decay products accumulated on the filter and from nonradiation-induced thermoluminescence. Typically the value for the control dosimeters is less than 5 percent of the value for the primary dosimeter unless the RDP concentration is very low. If the value for the control dosimeter exceeds approximately 5 percent of the value for the primary dosimeter for concentrations greater than 0.01 WL and on a regular basis, the cause should be investigated.

## 3.3 PROTOCOL FOR THE DETERMINATION OF INDOOR RADON DECAY PRODUCT CONCENTRATION BY GRAB SAMPLING

### 3.3.1 Purpose

This protocol provides guidance for using the grab sampling technique to provide accurate and reproducible measurements of indoor radon decay product (RDP) concentrations. Following the protocol will help ensure uniformity among measurement programs and allow valid intercomparison of results. Measurements made in accordance with this procedure will produce measurements of RDP concentration representative of standardized, closed-house conditions. Such measurements of closed-house concentrations have a smaller variability and are more reproducible than measurements made when the house conditions are not controlled.

### 3.3.2 Scope

This procedure covers, in general terms, the equipment, procedures, and quality control objectives to be used when performing measurements. This document provides guidelines to be incorporated into standard operating procedures. More information about the procedures may be obtained from the U.S. EPA Office of Radiation Programs (ANR-460), 401 M Street, S.W., Washington, D.C., 20460.

### 3.3.3 Method

Grab sampling measurements of RDP concentrations in air are performed by collecting the decay products from a known volume of air on a filter and by counting the activity on the filter following collection. Several methods for performing such measurements have been developed and have been described by George (Ge80b). Comparable results may be obtained using all these methods. This procedure, however, will describe two methods that have been most widely used with good results. These are the Kusnetz procedure and the modified Tsivoglou procedure.

The Kusnetz procedure (Ku56; ANSI73) may be used to obtain results in working levels (WL) when the concentration of individual decay products is unimportant. Decay products from up to 100 liters of air are collected on a filter in a 5-minute sampling period. The total alpha activity on the filter is counted at any time between 40 and 90 minutes after the end of sampling. Counting can be done using a scintillation-type counter to obtain gross alpha counts for the selected period. Counts from the filter are converted to disintegrations using the appropriate counter efficiency. The disintegrations from the decay products collected from the known volume of air may be converted into working levels using the appropriate "Kusnetz factor" (see Appendix B, Table B-1) for the counting time utilized.

The Tsivoglou procedure, as modified by Thomas (Ts53; Th72), may be used to determine WL and the concentration of the individual RDPs. Sampling is the same as that used for the Kusnetz procedure; however, the filter is counted three separate times following collection. The filter is counted between 2 and 5 minutes, 6 and 20 minutes, and 21 and 30 minutes following completion of sampling. Count results are used in a series of equations to calculate concentrations of the three RDPs and working level. These equations and an example calculation appear in Appendix B.

### 3.3.4 Equipment

Equipment required for RDP concentration determination by grab sampling consists of:

- An air pump capable of collecting samples at the desired flow rate.
- A filter holder to accept a 25 to 47-mm diameter, 0.8-micron membrane or glass fiber filter.
- A calibrated flow meter to determine air flow through the filter during sampling.
- A clock for accurate timing of sampling and counting.
- A scintillation counter (such as the Randam[a] Electronics Model SC-5, or the EDA[a] Instruments Model RD-200) and a zinc sulfide scintillation disc.
- A National Bureau of Standards (NBS)-traceable alpha calibration source to determine counter efficiency

### 3.3.5 Premeasurement Considerations

Prior to collection of the sample, proper operation of the equipment must be verified, and the counter efficiency and background must be determined. This is especially critical for the Tsivoglou procedure, in which the sample counting must begin 2 minutes following the end of sampling.

The air pump, filter assembly, and flow meter must be tested to assure there are no leaks in the system. The scintillation counter must be operated with the scintillation tray (where applicable) and scintillation disc in place to determine background for the counting system. Also, the counter must be operated with an NBS-traceable alpha calibration source in place of

---

(a) Use of trade names does not constitute EPA endorsement.

a filter in the counting location, to determine system counting efficiency. Both the system background and system efficiency are used in the calculation of results from the actual sample.

### 3.3.6 Measurement Criteria

The following conditions should exist prior to and during the sampling to ensure that the conditions are as standardized as possible.

- The sampling should be made under closed-house conditions. To a reasonable extent, external doors and windows should be closed during the 12 hours prior to the measurement (except for normal entrance and exit). Normal entrance and exit includes a brief opening and closing of a door, but an external door should not be left open for more than a few minutes. No windows or doors should be open during the sampling period. These conditions are expected to exist as normal living conditions during the winter in northern climates. For this reason and other reasons discussed in section 1.2.1, measurements should be conducted during the winter whenever possible.

- Internal-external air exchange systems (other than a furnace) such as high-volume attic and window fans should not be operated for at least 12 hours prior to and during the sampling.

- In southern climates or when measurements must be made during a warm season, the closed-house conditions are satisfied by meeting the preceding criteria. This condition can be most conveniently satisfied if the sampling is done after the occupant has been instructed to keep the windows closed and all internal-external ventilation systems off during the night and until after the measurement is made. Air conditioning systems that recycle interior air should not be operated prior to the measurement, if reasonable. No ventilation systems should be operated during the measurement. The closed-house conditions must be more rigorously verified and maintained, however, when they are not the normal living conditions.

- The sampling should not be conducted if severe storms with high winds have occurred in the previous 12 hours or are present at the sampling time.

### 3.3.7 Documentation

It is important that enough information about the measurement is recorded in a permanent log so that data interpretations and comparisons can be made. This information includes:

- o The time and date of the start and end of the measurement,
- o Whether standardized conditions, as previously specified, are satisfied,
- o Exact location of the measurement, on a diagram, of the room and house, if possible,
- o Other easily gathered information that may be useful, such as the type of house, type of heating system, existence of crawl space, occupants smoking habits, and operation of humidifiers, air filters, electrostatic precipitators, and clothes dryers.

### 3.3.8 Sampling Operations

#### 3.3.8.1 Location in Room

The sample should be collected in an area away from drafts. The sample should not be collected near heating, ventilation, or air conditioning (HVAC) vents, leaking windows and doors, clothes dryer or stove vents, fireplaces, etc. The sample should not be taken near the outside walls of the house. If possible, entrance into a basement room for sampling should be made through an interior stairway rather than an exterior door to reduce the ventilation caused by the opening of the door.

#### 3.3.8.2 Sampling

A new filter should be placed in the filter holder prior to entering the house. Care should be taken to avoid puncturing the filter and to avoid leaks. The sampling is begun by starting the pump and the clock simultaneously. Note the air flow rate and record it in a log book. Also record the time the sampling was begun. The sampling period should be 5 minutes, and the time from the beginning of sampling to the time of counting must be precisely recorded.

### 3.3.9 Analysis

Analysis may be done using the Kusnetz, modified Tsivoglou, or other procedure described elsewhere (Ge80b). If the Tsivoglou procedure is used, the counting must be started 2 minutes following the end of sampling. Analysis using the Kusnetz procedure must be performed between 40 and 90 minutes following the end of sampling. A counting time of 10 minutes during this period is usually used.

Remove the filter from the holder using forceps and carefully place it facing the scintillation phosphor. The side of the filter on which the decay products were collected must face the phosphor disc. The chamber containing the filter and disc should be

closed and allowed to dark-adapt prior to starting counting. For the Tsivoglou method this procedure of placing the filter in the counting position must be done quickly, since the first of the three counts must begin two minutes following the end of sampling. If the counter used has been shown to be slow to dark-adapt, the counting should be done in a darkened environment. Additional details on the procedure and calculations may be found in the references (Ku56; Ts53; Th72).

### 3.3.10 Grab Sampling Results

#### 3.3.10.1 Sensitivity

For a 5-minute sampling period (10 to 20 liters of air) on a 25-mm filter, the sensitivity using the Kusnetz or modified Tsivoglou counting procedure should be approximately 0.0005 working level (Ge80b).

#### 3.3.10.2 Precision

The coefficient of variation should not exceed 30 percent at RDP concentrations of 0.005 WL or greater. This precision should be monitored using the results of duplicate measurements described in section 3.3.11.2 of this protocol. Sources of error in the procedure may result from inaccuracies in measuring the volume of air sampled, characteristics of the filter used, and measurement of amount of radioactivity on the filter.

### 3.3.11 Quality Assurance

The quality assurance program for RDP concentration measurements by grab sampling includes calibration and duplicate measurements.

The U.S. EPA has established a Radon/Radon Progeny Measurement Proficiency Evaluation and Quality Assurance Program. This program will enable laboratories to demonstrate their proficiency at measuring radon and radon decay product concentrations and to have their quality assurance programs evaluated. Contact the U.S. EPA Office of Radiation Programs Quality Assurance Officer by calling (FTS or 703) 557-7380, or call 800-334-8571, extension 7131, for further information about this program.

#### 3.3.11.1 Calibration

Pumps and flow meters used to sample air must be routinely calibrated to assure accuracy of volume measurements. This may be performed using a dry-gas meter or other flow measurement device of traceable accuracy. This should be done every 6 months or after any instrument repair or modification.

The radiological counters should have calibration checks run daily to determine counter efficiency. This is particularly important for portable counters taken into the field that may be subject to rugged use and temperature extremes. These checks are made using an NBS-traceable alpha calibration source such as Thorium-230.

At least once per year, grab measurements should be made in a calibration chamber with known RDP concentrations to verify the calibration factor. These measurements should also be used to test the collection efficiency and self-absorption of the filter material being used for sampling. A change in the filter material being used during the year requires checking the new material for collection efficiency in a calibration chamber.

3.3.11.2 Duplicates

Duplicate grab samples should be collected with sufficient frequency to test the precision of the measurement. The number of duplicates should be at least 10 percent of the total samples collected. Care should be taken to ensure that the samples are duplicates to the greatest extent possible. The filter heads should be relatively close to each other and away from drafts. Care should also be taken to ensure that one filter is not in the discharge air stream of the other sampler.

Data from duplicate samples should be evaluated using the procedures recommended for internal quality control programs for replicate analysis (Ro65, EPA80). The method should achieve a coefficient of variation of 30 percent (1 sigma) or less. Consistent failure in duplicate agreement indicates an error in the measurement process that should be investigated.

## REFERENCES


ANSI73 American National Standards Institute, 1983, "American National Standard for Radiation Protection in Uranium Mines", ANSI N13.8-1973.

Be75 Beckman, R.T., "Calibration Procedures for Radon and Radon Daughter Measurement Equipment", U.S. Department of Interior, Mining Enforcement and Safety Administration Information Report 1005.

Co83 Cohen, B.L. and Cohen, E.S., 1983, "Theory and Practice of Radon Monitoring with Charcoal Adsorption", Health Physics, Vol. 45, No. 2.

EPA80 U.S. Environmental Protection Agency, 1980, "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans", Washington, D.C., QAMS-005/80.

Fl65 Fleischer, R.L., Price, P.B., and Walker, R.M., 1965, "Solid State Track Detectors: Applications to Nuclear Science and Geophysics", Annual Review of Science, pg.1.

Ge76 George, A.C., 1976, "Scintillation Flasks for Determination of Low Level Concentrations of Radon", in Proceedings of Ninth Midyear Health Physics Symposium, Denver, Colorado.

Ge80a George, A.C. and Breslin, A.J., 1980, "The Distribution of Ambient Radon and Radon Daughters in Residential Buildings in the New Jersey-New York Area", Natural Radiation Environment III, Vol. 2, p.1272, CONF-780442.

Ge80b George, A.C., 1980, "Radon and Radon Daughter Field Measurements", Paper presented at the National Bureau of Standards Seminar on Traceability for Ionizing Radiation Measurements", May 8-9, Gaithersburg, Maryland.

Ge83 George, J.L., 1983, "Procedures Manual for the Estimation of Average Indoor Radon Daughter Concentrations by the Radon Grab Sampling Method", Bendix Field Engineering Corp., Grand Junction, Colorado, GJ/TMC-11(83) UC-70A.

Ge84 George, A.C., 1984, "Passive, Integrated Measurements of Indoor Radon Using Activated Carbon", Health Physics, Vol. 46, No. 4.

Ku56 Kusnetz, H.L., 1956, "Radon Daughters in Mine Atmospheres - A Field Method for Determining Concentrations", American Industrial Hygiene Association Quarterly, Volume 17.

Lo69 Lovett, D.B., 1969, "Track Etch Detectors for Alpha Exposure Estimation", Health Physics, Vol. 16, pp. 623-628.

Lu57 Lucas, H.F., 1957, "Improved Low-Level Alpha Scintillation Counter for Radon, Review of Scientific Instruments", Vol. 28, p.680.

PHS57 Public Health Service, 1957, "Control of Radon and Daughters in Uranium Mines and Calculations on Biological Effects", PHS Report 494, U.S. Department of Health, Education and Welfare, Washington, D.C., pp.41-42.

Ro65 Rosenstein, M. and Goldin, A.S., 1965, "Statistical Techniques for Quality Control of Environmental Radioassay", Science, volume 2, pp 93-102.

Th72 Thomas, J.W., 1972, "Measurement of Radon Daughters in Air", Health Physics, volume 23, pg.783.

Ts53 Tsivoglou, E.C., Ayer, H.E., and Holaday, D.A., 1953, "Occurance of Nonequilibrium Atmospheric Mixtures of Radon and Its Daughters", Nucleonics, Volume 1, pg.40.

# APPENDIX A

## SUPPLEMENTARY INFORMATION FOR GRAB RADON SAMPLING

### EQUIPMENT

Equipment to measure radon concentration using grab sampling into scintillation cells is available from several commercial suppliers. Equipment required includes:

- o Scintillation cells
- o Pump to evacuate single valve cells or to flow air through double valve cells
- o Filter holder and filter to remove particulates
- o Detector-scaler-high voltage assembly for counting
- o Timer
- o Calibration cell or check source
- o Aged air or nitrogen

### GENERAL METHOD DESCRIPTION

- o Air to be sampled for radon is either flushed through a cell using a low volume air pump or is drawn into an evacuated cell through a filter.
- o The sample in the cell is allowed to equilibrate to optimize counting efficiency.
- o The cell is placed on a photomultiplier tube and scintillations counted.
- o Radon concentration is calculated based on the sample counts and corrected using appropriate ingrowth and decay factors.

### PROCEDURE

The procedure described below is that used by the U.S. Environmental Protection Agency Office of Radiation Programs in its field measurement programs. It is designed for measurements made using the Randam[a] Electronics Model SC-5 cell counters and associated cells or the EDA[a] Instruments Model RD-200 System.

---

(a) Use of trade names does not constitute EPA endorsement.

However, equipment is available from several suppliers, and it may be necessary to modify the procedure slightly to accomodate these differences. For example, the correct cell volume must be used in the calculations. A general procedure using the Randam or EDA equipment includes:

1. The cells to be used are flushed with aged air or nitrogen to remove traces of previous sample. It may be necessary to store cells for 24 hours prior to reuse if the cell had contained a high activity sample. Place each cell in counter, wait 2 minutes for the system to become dark adapted, and count background of the cell for 10 minutes. Record background data for each cell.

2. At the site to be surveyed, collect the sample by flowing air into the longer tube in the top of the EDA cell (double valve) for a period sufficient to allow 10 air exchanges. For the Randam (single valve) cells it is only necessary to open the valve on the evacuated cells and allow 10 to 15 seconds for complete filling. Cells must be filled with air forced through a filter to prevent entry of airborne particulates.

3. The filled cells must be allowed to equilibrate for 4 hours prior to counting. The cells should not be exposed to bright light prior to counting.

4. The cells are placed in the counters, the systems are allowed to dark adapt for 2 minutes, and the cells are counted. Counting time will vary based on the activity in the cell, however, at least 1,000 counts is desirable to provide good statistics.

5. The activity in the sample is calculated and corrected for ingrowth and decay as described below.

## CALCULATION OF RESULTS

The radon concentration in picocuries per liter is determined using the following formula:

$$pCi/l = \frac{cpm(s) - cpm(bkg)}{E} \times \frac{C}{A} \times \frac{1}{V}$$

where

cpm(s) = Counts per minute for the sample

cpm(bkg) = Counts per minute for background

E = Efficiency of system determine for each cell as described in Section 11.1 of the protocol. For the EDA and Randam cells the factor is typically 4-5 cpm/pCi.

C = Correction for decay during counting from table A-1.

A = Correction for decay of radon from time of collection to start of counting from table A-1.

V = Volume of counting cell in liters,

V = 0.170 1 for EDA cells
V = 0.125 1 for Randam cells

SAMPLE CALCULATION

The following sample calculation demonstrates the procedure for calculating results.

- Background Count for system = 10 counts in 10 minutes or 1 cpm
- Sample Count for 120 minutes = 1200 counts or 10 cpm
- System Efficiency (E) from cell calibration = 4.62 cpm/pCi
- Count time correction (C) for 120 minutes = 1.00757
- Delay time correction (A) for 4 hours = 0.97026
- Volume correction (V) for EDA cell = 0.170 1

$$\text{pCi/l} = \frac{10 \text{ cpm} - 1 \text{ cpm}}{4.62 \text{ cpm/pCi}} \times \frac{1.00757}{0.97026} \times \frac{1}{0.170 \text{ l}} = 11.9$$

Table A-1

## Radon Correction Factors

A. - Correction for radon decay from time of collection to start of counting

C. - Correction for radon decay during counting

| | A. | | | C. |
|---|---|---|---|---|
| Time | Minutes | Hours | Days | Hours |
| 0 | 1.00000 | 1.00000 | 1.00000 | 1.00000 |
| 1 | 0.99987 | 0.99248 | 0.83431 | 1.00378 |
| 2 | 0.99975 | 0.98502 | 0.69607 | 1.00757 |
| 3 | 0.99962 | 0.97761 | 0.58074 | 1.01136 |
| 4 | 0.99950 | 0.97026 | 0.48451 | 1.01517 |
| 5 | 0.99937 | 0.96296 | 0.40423 | 1.01899 |
| 6 | 0.99925 | 0.95572 | 0.33726 | 1.02281 |
| 7 | 0.99912 | 0.94854 | 0.28138 | 1.02665 |
| 8 | 0.99899 | 0.94140 | 0.23475 | 1.03050 |
| 9 | 0.99887 | 0.93432 | 0.19586 | 1.03435 |
| 10 | 0.99874 | 0.92730 | 0.16341 | 1.03821 |
| 11 | 0.99862 | 0.92033 | 0.13633 | 1.04209 |
| 12 | 0.99849 | 0.91340 | 0.11374 | 1.04597 |
| 13 | 0.99837 | 0.90654 | 0.09490 | 1.04986 |
| 14 | 0.99824 | 0.89972 | 0.07917 | 1.05377 |
| 15 | 0.99811 | 0.89295 | 0.06605 | 1.05768 |
| 16 | 0.99799 | 0.88624 | 0.05511 | 1.06160 |
| 17 | 0.99786 | 0.87958 | 0.04598 | 1.06553 |
| 18 | 0.99774 | 0.87296 | 0.03836 | 1.06947 |
| 19 | 0.99761 | 0.86640 | 0.03200 | 1.07342 |
| 20 | 0.99749 | 0.85988 | 0.02670 | 1.07738 |
| 21 | 0.99736 | 0.85342 | 0.02228 | 1.08135 |
| 22 | 0.99724 | 0.84700 | 0.01859 | 1.08532 |
| 23 | 0.99711 | 0.84063 | 0.01551 | 1.08931 |
| 24 | 0.99699 | 0.83431 | 0.01294 | 1.09331 |
| 25 | 0.99686 | 0.82803 | 0.01079 | 1.09732 |
| 26 | 0.99673 | 0.82181 | 0.00901 | 1.10133 |
| 27 | 0.99661 | 0.81563 | 0.00751 | 1.10536 |
| 28 | 0.99648 | 0.80950 | 0.00627 | 1.10939 |
| 29 | 0.99636 | 0.80341 | 0.00523 | 1.11344 |
| 30 | 0.99623 | 0.79737 | 0.00436 | 1.11749 |
| 31 | 0.99611 | 0.79137 | 0.00364 | 1.12155 |
| 32 | 0.99598 | 0.78542 | 0.00304 | 1.12562 |
| 33 | 0.99586 | 0.77951 | 0.00253 | 1.12971 |
| 34 | 0.99573 | 0.77365 | 0.00211 | 1.13380 |
| 35 | 0.99561 | 0.76784 | 0.00176 | 1.13790 |
| 36 | 0.99548 | 0.76206 | 0.00147 | 1.14201 |
| 37 | 0.99536 | 0.75633 | 0.00123 | 1.14613 |
| 38 | 0.99523 | 0.75064 | 0.00102 | 1.15026 |
| 39 | 0.99511 | 0.74500 | 0.00085 | 1.15440 |
| 40 | 0.99498 | 0.73940 | 0.00071 | 1.15854 |
| 41 | 0.99486 | 0.73384 | 0.00059 | 1.16270 |
| 42 | 0.99473 | 0.72832 | 0.00050 | 1.16687 |
| 43 | 0.99461 | 0.72284 | 0.00041 | 1.17105 |
| 44 | 0.99448 | 0.71741 | 0.00035 | 1.17523 |
| 45 | 0.99435 | 0.71201 | 0.00029 | 1.17943 |
| 46 | 0.99423 | 0.70666 | 0.00024 | 1.18363 |
| 47 | 0.99410 | 0.70134 | 0.00020 | 1.18784 |
| 48 | 0.99398 | 0.69607 | 0.00017 | 1.19207 |
| 49 | 0.99385 | 0.69084 | 0.00014 | 1.19630 |
| 50 | 0.99373 | 0.68564 | 0.00012 | 1.20054 |
| 51 | 0.99360 | 0.68049 | 0.00010 | 1.20479 |
| 52 | 0.99348 | 0.67537 | 0.00008 | 1.20905 |
| 53 | 0.99335 | 0.67029 | 0.00007 | 1.21332 |
| 54 | 0.99323 | 0.66525 | 0.00006 | 1.21760 |
| 55 | 0.99310 | 0.66025 | 0.00005 | 1.22189 |
| 56 | 0.99298 | 0.65528 | 0.00004 | 1.22618 |
| 57 | 0.99286 | 0.65036 | 0.00003 | 1.23050 |
| 58 | 0.99273 | 0.64547 | 0.00003 | 1.23481 |
| 59 | 0.99261 | 0.64061 | 0.00002 | 1.23914 |
| 60 | 0.99248 | 0.63579 | 0.00002 | 1.24347 |

APPENDIX B

SUPPLEMENTARY INFORMATION FOR
GRAB RADON DECAY PRODUCT SAMPLING

EQUIPMENT

a. Air sampling pump - A pump capable of maintaining a flowrate of 2 to 25 liters per minute through the selected filter is required. The flowrate should not vary significantly during the sampling period. A calibrated air flow measurement device is also required.

b. Filters and filter holder assembly - Membrane type filters are recommended with a pore size not exceeding 0.8 microns and a filter holder assembly suitable for the type of filters being used. Adapters for attachment of the filter holder to the pump are also required.

c. Alpha counting system - A detector and scaler timer system is required that can accurately measuring the alpha particles emitted by radon decay products on a filter. The counting system must be calibrated and the efficiency should not vary significantly with alpha energy over the range of 4 to 7 MeV. Downward-looking detectors with a mylar seal are very energy dependent, and if such detectors are used the efficiency is best determined using Po-214.

d. Timer - A stopwatch or timer to measure the sampling time and time after sampling is required.

GENERAL DESCRIPTION OF METHODS

Two methods commonly used are described below. There are several other methods reported in the literature. Sampling in these methods requires collection of radon decay products on a filter and measuring the alpha activity of the sample with a calibrated detector at time intervals that are specific for each method. The results of the alpha measurement and the sample volume are treated with calculations that are also specific for each method to determine the working level.

PROCEDURE

a. Sample Collection:

i. Install the filter in the filter holder assembly and attach to the pump.

ii. Operate the pump for exactly 5 minutes pulling air through the filter. Record starting time and air flow rate.

iii. Stop the pump at the end of the 5 minute sampling time and start or reset the stopwatch.

Note: Sample counting and analysis for two different techniques are described.

b. Sample Counting - Modified Tsivoglou Technique

i. Carefully transfer the filter from the filter holder assembly to the detector. Orient the collection side of the filter toward the face of the detector.

ii. Operate the counter for the following time intervals, after sampling stopped: 2 to 5 minutes, 6 to 20 minutes, and 21 to 30 minutes. Record the total counts for each time period.

c. Sample Counting - Kusnetz Technique

i. Carefully transfer the filter from the filter holder assembly to the detector. Orient the collection side of the filter toward the face of the detector.

ii. Operate the counter over any 10 minute time interval between 40 minutes and 90 minutes after sampling starts. Record the total counts for the sample and the time (in minutes after sampling) at the center of the 10 minute time interval.

d. Data Analysis - Modified Tsivoglou Technique

The concentration in pCi/l of each of the radon decay products, Po-218, Pb-214, and Po-214 can be determined by using the following calculations:

$$C_2 = \frac{1}{FE}\,(0.16746\,G_1 - 0.0813\,G_2 + 0.0769\,G_3 - 0.0566R)$$

$$C_3 = \frac{1}{FE}\,(0.00184\,G_1 - 0.0209\,G_2 + 0.0494\,G_3 - 0.1575R)$$

$$C_4 = \frac{1}{FE}\,(-0.0235\,G_1 + 0.0337\,G_2 - 0.0382\,G_3 - 0.0576R)$$

Note: The constants in these equations are based on a 3.11 minute half-life of Po-218, and are therefore slightly different than those used by Thomas (Th72).

The working level associated with these concentrations can then be calculated using the following relationship:

$WL = (1.028 \times 10^{-3} \times C_2 + 5.07 \times 10^{-3} \times C_3 + 3.728 \times 10^{-3} \times C_4)$

where:

$C_2$ = concentration of Po-218 (RaA) in pCi/l
$C_3$ = concentration of Pb-214 (RaB) in pCi/l
$C_4$ = concentration of Po-214 (RaC') in pCi/l
F = sampling flow rate in lpm
E = counter efficiency in cpm/dpm
$G_1$ = gross alpha counts for the time interval 2 to 5 minutes
$G_2$ = gross alpha counts for the time interval 6 to 20 minutes
$G_3$ = gross alpha counts for the time interval 21 to 30 minutes
R = background counting rate in cpm

Reference: (Th72).

e. Data Analysis - Kusnetz Technique

Calculate WL as follows:

$$WL = \frac{C}{K_{(t)} V E}$$

where

C = Sample cpm - Background cpm

$K_{(t)}$ = Factor determined from Table B-1 for time from end of collection to midpoint of counting

V = Total sample air volume in liters from:

flow rate (l/m) x sample time (m)

E = Counter efficiency in cpm/dpm.

TABLE B-1

Kusnetz Factors (PHS57)

| Time | $K_{(t)}$ |
|---|---|
| 40 | 150 |
| 42 | 146 |
| 44 | 142 |
| 46 | 138 |
| 48 | 134 |
| 50 | 130 |
| 52 | 126 |
| 54 | 122 |
| 56 | 118 |
| 58 | 114 |
| 60 | 110 |
| 62 | 106 |
| 64 | 102 |
| 66 | 98 |
| 68 | 94 |
| 70 | 90 |
| 72 | 87 |
| 74 | 84 |
| 76 | 82 |
| 78 | 78 |
| 80 | 75 |
| 82 | 73 |
| 84 | 69 |
| 86 | 66 |
| 88 | 63 |
| 90 | 60 |

## MODIFIED TSIVOGLOU TECHNIQUE
## SAMPLE PROBLEM

$F$ = Sampling Flow Rate = 3.5 lpm

$E$ = Counting Efficiency = 0.47 cpm/dpm

$G_1 = 880$

$G_2 = 2660$

$G_3 = 1460$

$R = 0.5$

$$C_2 = \frac{1}{3.5 \times 0.47}(0.16746 \times 880 - 0.0813 \times 2600 + 0.0769 \times 1460 - 0.0566 \times 0.5)$$

$C_2 = 26.3$ pCi/l

$$C_3 = \frac{1}{3.5 \times 0.47}(0.00184 \times 880 - 0.0209 \times 2660 + 0.0494 \times 1460 - 0.1575 \times 0.5)$$

$C_3 = 11.0$ pCi/l

$$C_4 = \frac{1}{3.5 \times 0.47}(-0.0235 \times 880 + 0.0337 \times 2660 - 0.0382 \times 1460 - 0.0576 \times 0.5)$$

$C_3 = 8.0$ pCi/l

$$WL = (1.028 \times 10^{-3} \times 26.3 + 5.07 \times 10^{-3} \times 11.0 + 3.728 \times 10^{-3} \times 8.0)$$

$WL = 0.113$

## KUSNETZ TECHNIQUE
## SAMPLE PROBLEM

- Background Count = 3 counts in 5 minutes or 0.6 cpm

- Standard Count = 5,985 counts in 5 minutes or 1,197 cpm

- Efficiency = $\frac{1,197 \text{ cpm} - 0.6 \text{ cpm}}{2,430 \text{ dpm}}$ = 0.49 (known source of 2430 dpm)

- Sample Volume = 4.4 liter/minute x 5 minutes = 22 liters

- Sample Count at 45 minutes (time from end of sampling period to midpoint of counting period) = 560 counts in 10 minutes or 56 cpm

- $K_{(t)}$ at 50 minutes from Table B-1 = 130

$$WL = \frac{56 \text{ cpm} - 0.6 \text{ cpm}}{130 \times 22\ 1 \times 0.49} = 0.04$$

* U.S. Government Printing Office: 1989—491-191/82931